# MAGNETIC CORES AS ELEMENTS OF DIGITAL COMPUTING SYSTEMS

BY

MUNRO KING HAYNES

B.S., University of Rochester, 1947
M.S., University of Illinois, 1948

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN ELECTRICAL ENGINEERING
IN THE GRADUATE COLLEGE OF THE
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# MAGNETIC CORES AS ELEMENTS OF DIGITAL COMPUTING SYSTEMS

In the course of the tremendous growth of interest and investment in the field of automatic high speed computing machinery in recent years, a need has arisen for new basic elements to replace vacuum tubes, in digital computing systems, with higher reliability and lower power dissipation, but with equal flexibility and speed of operation. The most serious disadvantage of vacuum tube systems is the ever-present likelihood of a tube failure, requiring error detection, trouble-shooting, replacement, and often re-running of problems. The Eniac, for example, containing 18,000 vacuum tubes is inoperative 15 percent of the time, largely from tube failures.

The purpose of this research has been the investigation of a new type of magnetic alloy core material with a rectangular hysteresis loop, just recently become available commercially under the trade-name "Deltamax", with the prospect of fulfilling the requirements for replacing a large proportion of the vacuum tubes currently used in computing equipment by the use of magnetic cores. These are inherently passive devices with the ability to store energy; have no hot cathode to require power, produce heat, or cause failure; require no steady power drain, needing power only to change the energy which they store; and have an indefinitely long life as far as is known.

The basic magnetic properties of Deltamax were first investigated, determining the hysteresis loop and response to current pulses — the ampere-turns and voltage-per-turn required to reverse the direction of flux in various pulse times. During these measurements it was discovered that reversible magnetic flux transformations can be performed under certain conditions, and possible uses of this discovery were investigated.

Attention was next turned to the design of basic magnetic

core circuits and the attendant problems of transferring information from one core to another, of controlling such transfers, and of performing binary logical operations. Vacuum tubes were at first used as combined gating and linking devices. In order to eliminate tubes used for linkage alone where no gating was required, a direct linkage using linking coils and rectifiers between cores was then used — a method developed at Harvard for transfer in a magnetic static delay line. A method of accomplishing multiple inputs and outputs by direct linkages and a method of applying gating control to the direct linkage system were then worked out. Several modified magnetic core circuits were developed to perform binary logical operations, and the design of such logical operation circuits analyzed using the logical notation developed by Aiken and others in analysis of vacuum tube operators.

Using these principles three types of shifting registers were designed, and one was constructed using no linkage tubes and only three vacuum tube current sources. In designing an adding system, the serial nature of magnetic core operations made necessary the use of "half-adder" type circuits. Using the magnetic core logical operation circuits several half-adders were designed, the last and best of which was built and tested. The remaining arithmetic unit component, a complement system, was solved by a change in the input circuit of the adder, and the modification of a shifting register, by use of a logical operator circuit, to function as a memory register with the ability to form complements. Then work was completed for integration of the components into the design of a complete magnetic core arithmetic unit.

By use of the reversible magnetic transformations discovered, a method was developed of repeatedly sensing the remanent flux direction of a core an indefinite number of times without changing the direction, or decreasing the magnitude, of the remanent flux. Using this as a read-out method, a system for making a static magnetic memory unit has been described. Since this system would have had an impractically long read-in time, it was not further investigated, but future development

of a better read-in method may render the system useful.

In basic magnetic core circuits, three fundamental ideas have been discovered. They are: (1) Means of controlling transfer between cores, allowing information to be transferred at will through combinations of cores by use of multiple input and output circuits and by judicious timing of current pulses to prevent undesired transfers. (2) Means of performing binary logical operations with magnetic cores, and the basic design principles for such circuits. A new linkage connection allows control of read-in from one core to another depending on the information digit present in a third core. (3) Design of the three basic components of the arithmetic unit of a parallel binary digital computer, the shifting registers, half-adders, and complement system, using controlled transfers and binary logical operations as fundamental processes.

The arithmetic unit problem has been solved in that a complete magnetic core arithmetic unit can be built with as few as fifteen vacuum tube current sources, using sixteen magnetic cores per binary digit. The main parts, the shifting register and half-adder, have been constructed in experimental models of five digit capacity and satisfactorily tested for over $10^7$ operations without error. In the tests more troubles were experienced in the tube-containing control circuits used than in the magnetic core units themselves. A forty-digit arithmetic unit built on the design of these models, using 640 cores and 15 current sources, would have an average addition time of 900 $\mu$s and an average multiplication time of 10,600 $\mu$s, with no further increase in speed. As explained in the full text, these times should be readily reducible by a factor of ten, since no effort was made for maximum speed in this work.

The investigation has shown that magnetic core circuits using Deltamax (or similar) material may successfully replace vacuum tubes in a large number of computer applications with expected higher reliability, practically indefinite life, and lower power requirements, but with slower speed of operation by about a factor of five. The design principles for use of such

cores have been established, and a complete magnetic core arithmetic unit designed by their use.

## VITA

Munro King Haynes was born on December 10, 1923, in Elmira, New York. After graduating from Lansingburgh High School, Troy, New York, in 1941, he entered The University of Rochester, Rochester, New York. In 1943 he enlisted in the Army of the United States and served with the Signal Corps in the American and Western Pacific Theaters. Upon discharge from the Army in 1946, he returned to The University of Rochester and received the degree Bachelor of Science in Physics in June 1947 from that institution. He then entered the Graduate College of the University of Illinois, and received the degree Master of Science in Electrical Engineering in August 1948. He held a Research Assistantship from September 1948 to September 1949, and a University Fellowship in the academic year 1949-50.

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